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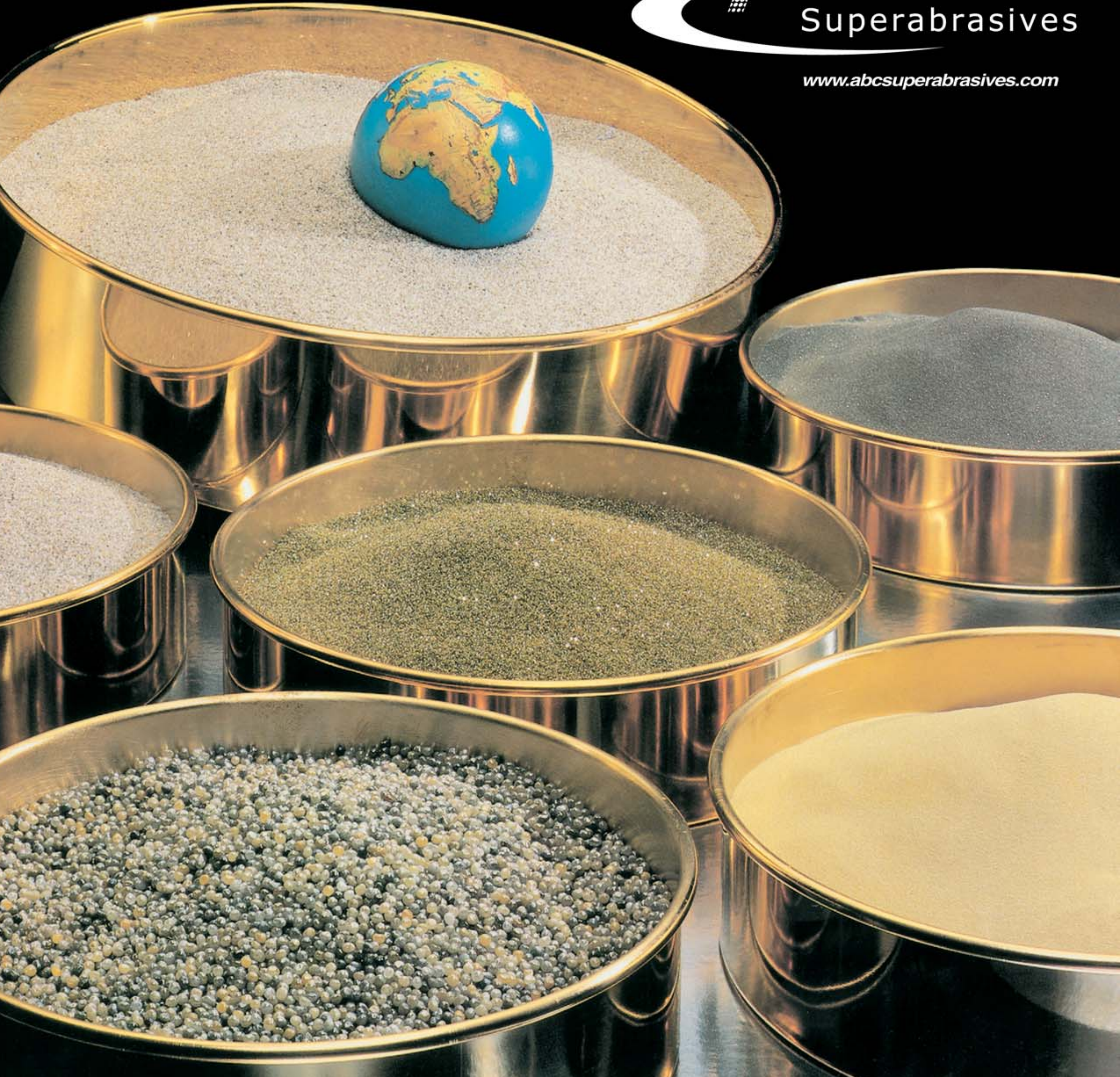

FINER POINTS

1946 60th ANNIVERSARY 2006
INDUSTRIAL DIAMOND ASSOCIATION OF AMERICA, INC.

"The ONLY magazine dedicated solely to the technology and application of superabrasives."

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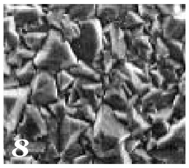
FINER POINTS is the only publication devoted exclusively to the understanding, selection and application of diamond, cubic boron nitride and related materials. It is edited for recipients who are involved in some way with these "superabrasives", either as providers of the materials, producers of products containing the materials or users of these products (e.g., grinding wheels, dressing tools, drill bits, saw blades, sawing wires, cutting tools, polishing compounds, CVD film products, etc.).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COVER PHOTO

Photo courtesy of Advanced Superabrasives showing precision plated tools containing diamond and cubic boron nitride used for precise work on a variety of materials in most manufacturing applications.

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A Finer Point of View…

The word 'value' has become cliché. Value has lost its power, relinquished its connotation, fallen victim to commoditization. The benefit of value is haphazardly communicated by supply chain participants who are being encouraged to reevaluate its definition and understand its relation to their offering. Customers are more inclined today than ever to evaluate what value means to them. The cost value analysis dominates today's purchase decision process. But can those of us facing the customer, whether directly or indirectly, intelligently explain the value of our product or service? Revisit what value means to you as a consumer, and apply this standard to your product or service. The result will represent a distinction that defies commoditization.

The value of yesterday has changed and requires a new approach, a new way of doing business. A technical model exists that defines whether a superabrasive product offers a rich value. New products are required to fulfill unique demands. Previously ignored applications change and are becoming superabrasive candidates. Conventional abrasive applications can be increasingly converted to value-added superabrasives. Ultimately, the consequential value of superabrasives increases productivity for the end user via scrap reduction, quality enhancement and increased throughput. These value-inducing elements constitute a technical equation supporting a healthy business model that warrants sound payment about which the end user feels confident. Devaluing elements have to be recognized in business practices through heightened awareness and an understanding that blankets the entire organization. An example is shifting share through buying business or lowering prices, which ultimately leads to value erosion. Lowering prices across a value chain was oftentimes a valid response to market demands, but this measure has done nothing to help the reputation of superabrasives with regard to value or increased total productivity.

PRESIDENT
Martin Deakins

A commercial model should also be employed to help define the value equation. Global economies and industries have forced a profound shift in the superabrasives industry. Superabrasive companies are confronted by unconventional demands, which call for innovative products. The cost of research, upgraded and new machinery, product testing, and manufacturing of specialized superabrasives products must be satisfied in order to provide innovation. Finally, the act of value selling should be understood by each constituent of the supply chain to give merit to the superabrasives advantage.

We are all affected by the economic realities of today. Escalated raw material costs, inflated fuel costs, and imbalanced currency exchanges challenge the way we operate. Total value once again consumes a large part of the overall process cost and should be a major driver in the purchasing decision. The less money a person has to spend, the more crucial value is in the purchasing equation. Technical and commercial models will outline the current-day values associated with your offerings. Revisit what value means to your customer and redefine the value surrounding your product or service. Success awaits you!

Sincerely,

Martin Deakins

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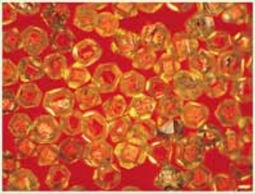

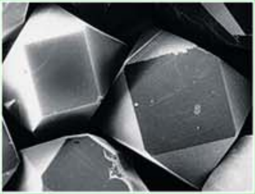

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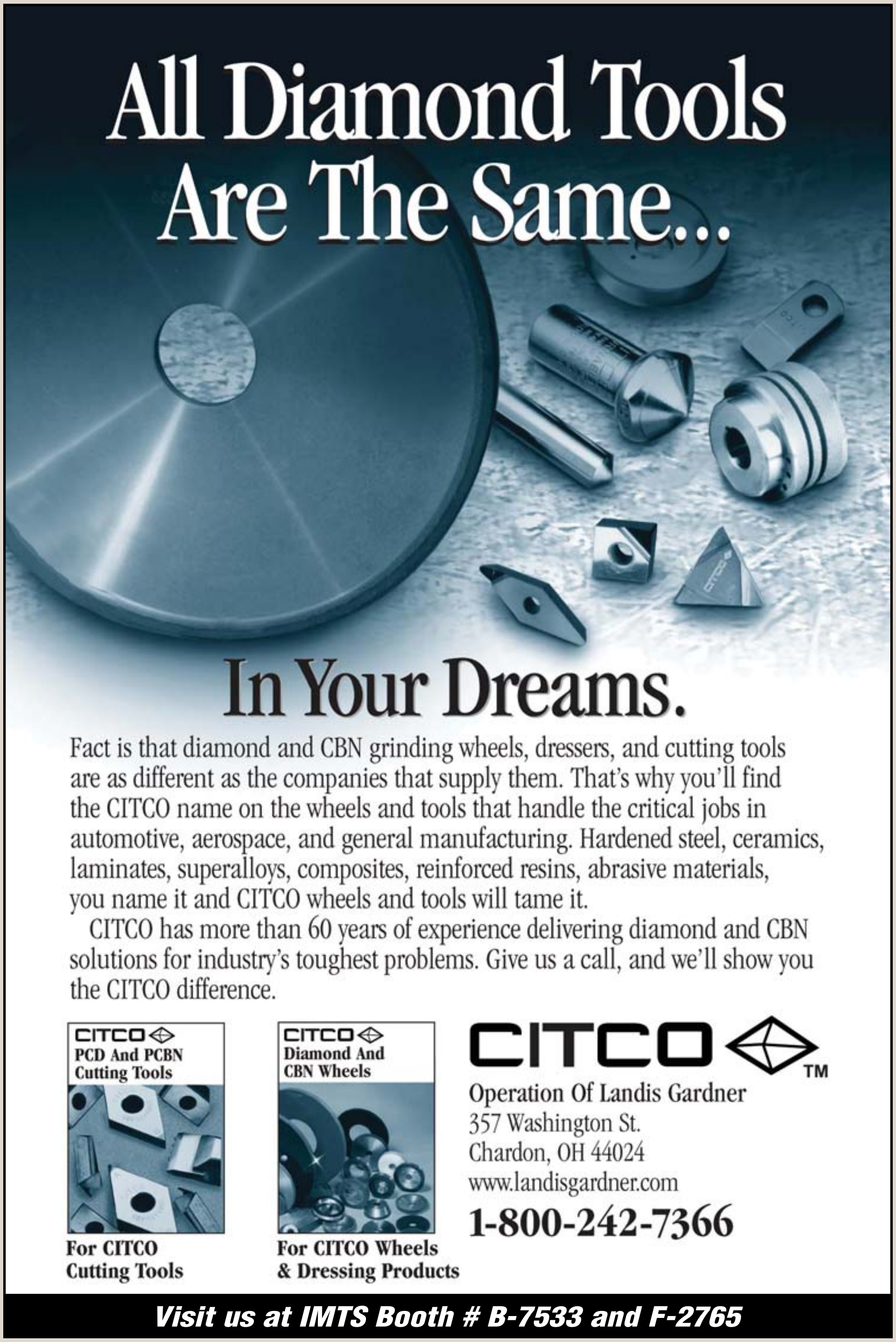
Editorial

TERRY KANE, Editor

IMTS - A Global Village of Technology

Over the years I have seen JIMTOF in Japan, EMO in Europe and of course the IMTS in the USA. At each of these shows the main attraction had always been machines and more machines. In fact, one of my treats was always to go and find the biggest machine and try to figure out how they managed to transport and move it unto the show floor. Most of us old-timers still remember when IMTS was the International Machine Tool Show. There were the standard machines that mill, machine, grind, hone, cut, shape and polish. Then there were the newer machines that EDM, EDG, laser cut, measure, balance or apply water jets. Recent history has shown the focus broaden as "manufacturing technology" became the buzz. IMTS even changed its name to the International Manufacturing Technology Show to highlight not only machines, but also technology. I took note in 2006 of an Emerging Technology area where universities and research facilities were showcasing their work on new materials and applications that addressed technology that was not only on the "cutting edge" so to speak but gave visitors an insight to what may be coming to the production floor in the not too distant future. There were also a couple of organizations that were showcasing the training needed to properly implement many of the new materials and applications. I was particularly interested in this area because I found it to be so much in line with what the Industrial Diamond Association has been preaching and practicing over the last few years. I saw most of these universities or research organizations had been working on developing products and materials that were classified as superabrasives and showing results of increased productivity and improved performance. These research companies are not just located in the USA, they are spread throughout the world and as we have seen from major conferences such as INTERTECH in the Americas, Diamond at Work in Europe and the 5th ZISC in the Pacific, there is no shortage of great new ideas and revolutionary products that will change the manufacturing world as we know it today. When you go to IMTS this year, don't pass by any "technology" related exhibits. Keep in mind that new technology makes those machines even more impressive. I heard an interesting analogy a few years ago. I stopped and was looking at a high-tech machine with computer control, self truing, high speed spindles, high pressure coolant delivery, automatic tool change heads, in-cycle measurement adjustments, automatic feed, final tool conveyors and every other high production capability you could imagine. The strange thing, for some reason, this machine was running a conventional aluminum oxide wheel. I made a comment to another show visitor standing next to me that this was curious and his reply was: "that's like putting wooden wagon wheels on a Ferrari". I guess that hits the nail on the head. When IMTS comes to Chicago this September I am sure the high-tech machines will be there as always and I am sure the vast majority of those machines will be applying superabrasives, from diamond and cubic boron nitride to polycrystalline diamond and polycrystalline cbn. I won't be surprised to see a few CVD diamond tools as well and most assuredly we'll see polycrystalline materials and CVD diamond being cut and shaped by a few laser machines. I also want to see a few of those new vacuum furnaces and induction brazing units that make the new generation of cutting tools. I want to see new technology all over the place and I am also curious to see what is offered by our colleagues from across the seas. When the world comes to Chicago I expect to be treated to a global village of technology.



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NEWS and notes

CYRUS JILLA NAMED AS NEW CEO OF ELEMENT SIX – The Board of Element Six SA, an independently managed joint venture between De Beers SA (majority shareholder) and Umicore SA, today announced that Christian Hultner, the CEO of Element Six, will leave the company on September 30th 2008 and has named Cyrus Jilla as the new CEO effective October 1st 2008. Christian Hultner will remain on the Element Six Board as a non-executive director. Mr. Jonathan Oppenheimer, non-executive chairman in recognising Christian Hultner's substantial contribution to Element Six, over his eight years of service, said, "During Christian Hultner's tenure, he has led Element Six through a period of transformation, establishing the company as the undisputed market leader in supermaterials, outperforming all its peers, and creating a company with excellent long-term growth prospects." Prior to joining Element Six, incoming CEO Cyrus Jilla has spent most of his career with Bain & Company, the global business consultants, most recently as Managing Partner of their London office. He is an acknowledged expert in strategy & company transformations and has strong mergers & acquisitions experience. Cyrus has advised De Beers and the Element Six management since 1999, and he has served as a non-executive director of Element Six since 2003. Previously, Cyrus worked for Schroders plc, the investment bank. Cyrus will also join the De Beers SA Executive Committee. On Cyrus Jilla's appointment, Mr. Oppenheimer went on to say, "We are truly delighted that Cyrus has accepted the role as CEO of Element Six. With his service as a non-executive director, Cyrus already has an in-depth knowledge of the business. Cyrus brings extensive strategic and leadership capability that will be invaluable to Element Six in meeting the challenges of the future." For more information contact: John Caldwell, Corporate Communications Manager, Element Six Ltd Tel: +353 (61) 460015 www.e6.com

DAN HERZOG JOINS WORLDWIDE SUPERABRASIVES – Worldwide Superabrasives a Global Supplier of high quality diamond and cBN grinding products, is pleased to announce that Dan Herzog has joined the company as Regional Sales Manager, taking responsibility for customers in the Midwest region of the U.S.A. Dan brings approximately 40 years of experience in the superabrasives industry to Worldwide. After receiving his BSME, he began his career with Cincinnati Milacron as a Design Engineer in the Special Grinding Machine Division. He then joined GE Superabrasives (now Diamond Innovations) as a Project Engineer for the Borazon CBN section, launching a 13-year period of concentration on superabrasives. At GE, Dan served in Market Development for the Compax Product Section before being named Pacific Sales Manager and then European Sales Manager. In 1986 Dan became President of Wendt and directed its growth to the dual operation of Wendt Dunnington and Wendt Diacraft. He briefly joined Abrasive Technology in a Leadership role, responsible for Sales and Market Development. During his superabrasives career Dan was instrumental in formation of the Unified Abrasive Manufacturer's Association and he served two terms as its President. He also served as President of the Industrial Diamond Association of America and was its chairman of the Standards Development Committee. In this role he worked to coordinate the efforts of the IDA, UAMA and ANSI in drafting and updating the industrial standards for superabrasives and superabrasive products. Dan now brings his considerable experience to serve the customers of Worldwide Superabrasives. Contact: Worldwide Superabrasives LLC, Fort Lauderdale, Fl, Tel: 954-828-9650, Email: info@worldwidesa.com Web: www.worldwidesa.com

ADVANCED SUPERABRASIVES – Henderson Nevada has introduced a new brochure outlining their line of Diamond and CBN Superabrasives tooling. The brochure details their in house manufacturing capabilities as an industry leader along with the company's commitment to enhancing future growth and customer support. For more details contact Advanced Superabrasives, Inc., 200 Sunpac Avenue, Henderson, NV 89011, USA Phone: 702-564-7735, Fax: 702-564-8422 Website: www.advanced-sa.com

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The Science of Precision

APPLIED DIAMOND AWARDED STRATEGIC FUND FROM THE STATE

Dover, Delaware – Governor Ruth Ann Minner joined Judy McKinney-Cherry, director of the Delaware Economic Development Office, to recognize Joseph W. Tabeling, president of Applied Diamond, Inc., for the company's scientific advancement and technological innovation at an event today in Wilmington, Del. "Applied Diamond has a sizable impact on our economy and by making an investment in the company's research, we expect that impact to grow significantly," said Governor Ruth Ann Minner. "The kind of research performed by small technology-based companies like Applied Diamond will bring innovative new products, jobs and revenue to Delaware." Applied Diamond provides synthetic diamond products and materials to U.S. Government, university, and corporate laboratories for high energy, optical and thermal applications such as targets and windows, analytical instrumentation and heat spreaders. Applied Diamond clients are located worldwide including the Americas, Europe and Asia. The development of sub-micron thick diamond film products will offer high-performance diamond foils to allow experiments to be run with beams (x-rays, photons, neutrons and heavy ions) of higher energy. For more information, visit dedo.delaware.gov.

SP3 DIAMOND TECHNOLOGIES RECEIVES MULTIPLE ORDERS FOR HOT FILAMENT CVD DIAMOND DEPOSITION TOOL – sp3 Diamond Technologies, Inc., a leading supplier of diamond film products, equipment and services, today announced two new orders for its Model 650 hot filament chemical vapor deposition (HFCVD) diamond reactor. The first order was received from the India Institute of Technology (IIT) Madras, which will install one system as part of the expansion of its Nano Functional Materials Technology Centre (NFMTC). The second order comes from an unnamed Japanese manufacturer. "These orders highlight the increasing interest not only in the material itself, but also in a product capable of delivering large scale and cost effective thin film diamond deposition," said Dwain Aidala, president and COO of sp3 Diamond Technologies. For more information about the company and its products and services please visit www.sp3inc.com

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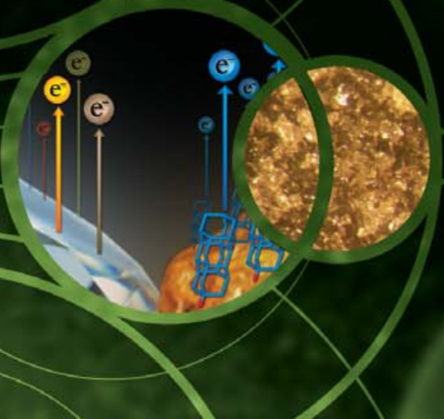
Following the success of previous conferences held in Barcelona and Rome, Diamond At Work is pleased to announce that the 3rd International Industrial Diamond Conference will take place in April 2009 in Paris, France. As before, the conference will embrace both the traditional abrasive applications of diamond as well as the newer technology-based applications.

Call for Papers

All members of the industrial diamond community are invited to participate in this conference by presenting the results of their work to industry experts and leading scientists. Details of submission of abstracts can be found on the Diamond At Work website.



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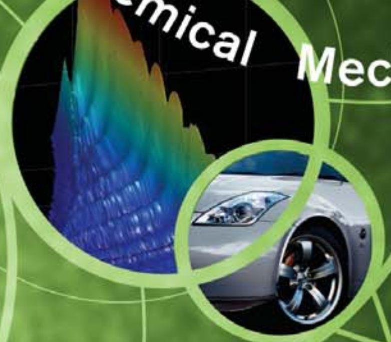

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CSIRO'S LIGHT METALS FLAGSHIP RECENTLY SHOWCASED TECHNOLOGIES THAT OFFER HIGHPERFORMANCE, LIGHTWEIGHT CAR COMPONENTS AT THREE US AUTOMOTIVE INDUSTRY CONFERENCES.

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"Our technologies use magnesium and aluminum alloys to create strong, lightweight car parts which are costcompetitive with structural components made of steel, and perform equally well," said Mr Barrie Finnin, until recently General Manager for Alloy Technologies with CSIRO Materials Science & Engineering. "We aim to get the best performance out of lighter metals with efficient manufacturing techniques and minimum waste of materials." Lightweight vehicle design - replacing existing automotive structural parts with light metal alternatives - is one of several complementary approaches to achieving lower fuel consumption. Lighter cars use less fuel because they need less energy to start and stop than heavier cars. Internationally, the automotive industry sees use of light metals and light alloys for car and truck components as a key means of creating of more fuel-efficient cars, through specific initiatives including the US FreedomCAR project and the NADIA European project. **For further information visit: http://www.csiro.au/news/LighterCars.html**

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Calendar of EVENTS

To have your event or conference listed, please send information to: Finer Points Event Calendar • P.O. Box 29460, Columbus OH 43229 • Fax 614-797-2264 or email: tkane-ida@insight.rr.com

September 5-7, 2008 5th ZISC
Songshan Hotel, Zhengzhou China
http://www.idacn.org/huiyizhuanlan/hotel.php

September 7-11, 2008
Sitges, Spain
www.diamond-conference.elsevier.com

September 8-13 IMTS 2008
International Manufacturing Technology Show • McCormick Place
Chicago, IL USA
www.imts.com

September 23-26 WIRE China 2008
The 3rd All China-International Wire & Cable
Shanghai New International Expo Center
Shanghai, P.R.China
http://www.wirechina.net

2009

February 3-6, 2009
Las Vegas Convention Center
Las Vegas, NV USA
www.worldofconcrete.com

MARCH 9-11, 2009
Industrial Diamond Association of America
Annual Meeting
The Colony
Long Boat Key, Florida USA
www.superabrasives.org

3rd International
Industrial Diamond Conference
16-17th April 2009 Paris France

April 16-17, 2009 3rd Diamond at Work
Etoile Meridien Hotel
Paris, France
www.diamondatwork.com

April 25-30, 2009 Interwire 2009
I-X Center • Cleveland, Ohio, USA
www.wirenet.org

2009 Offshore Technology Conference
4-7 May :: Reliant Park :: Houston, Texas, USA

May 4-7, 2009
Offshore Technology Conference
Houston, TX USA • www.otcnet.org/2009

September 8-11, 2009 Stone Tec
Exhibition Center Nuremberg
Nuremberg Germany • www.stone-tec.com

CALENDAR EVENTS for 2010

MARCH 13-14, 2010
Industrial Diamond Association of America
Annual Meeting
The Ritz Carlton Lake Las Vegas • Henderson, NV USA
www.superabrasives.org

INTERTECH 2010
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March 15-17, 2010

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7. Diamond saw blades
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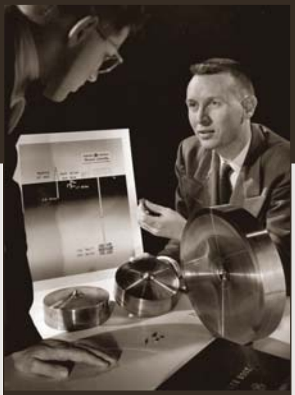
IN MEMORIAM

H. TRACY HALL

October 20, 1919 to July 25, 2008



TRACY wih Belt Apparatus

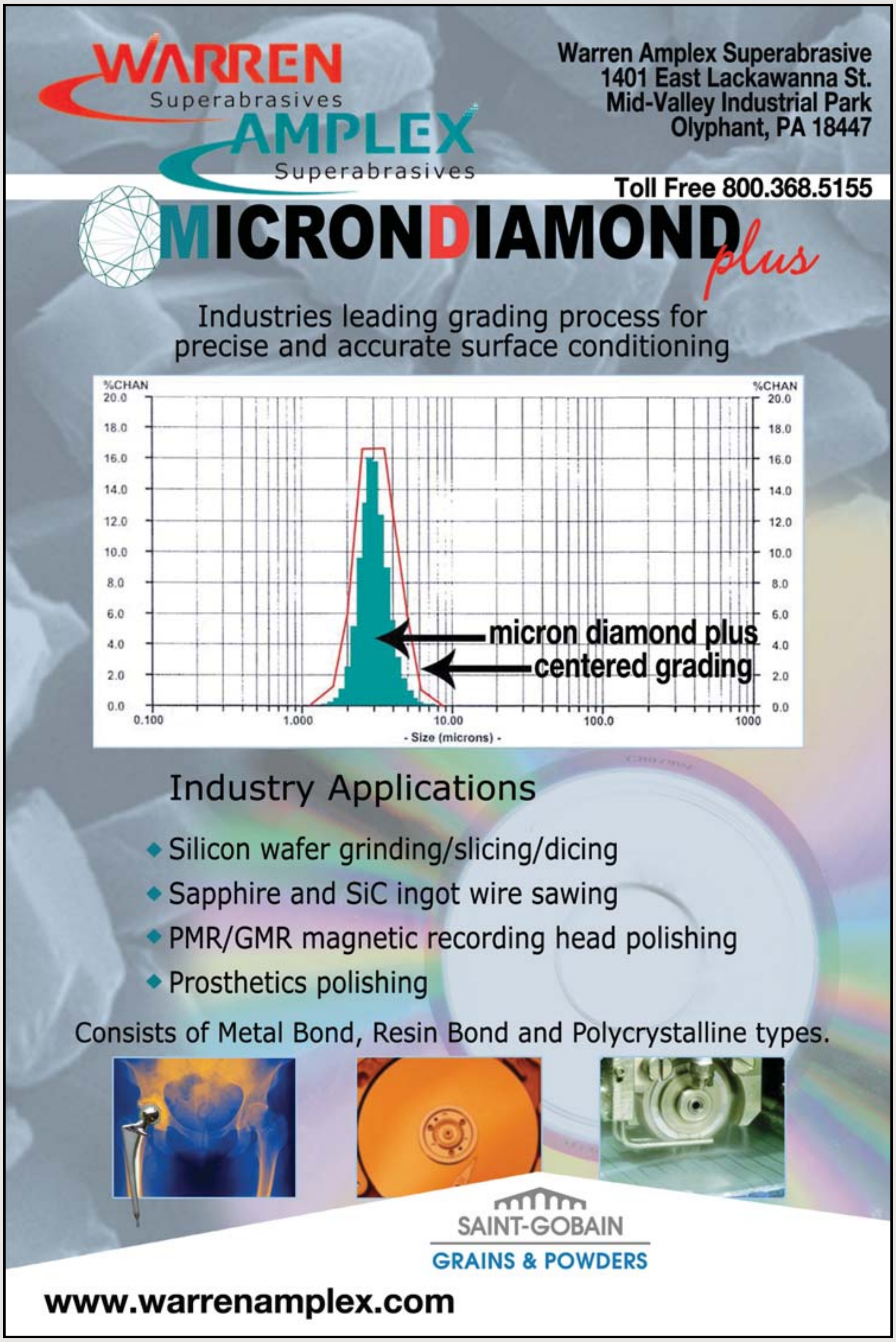
DR. HALL being congratulated by CHRISTIAN HULTNER of E6 at the 50th Anniversary of the first diamond synthesis.

The diamond industry has lost one of its most famous and iconic figures. Dr. H. Tracy Hall proved to be a great scientist, a humanitarian, a spiritual leader and a respected family man. H. Tracy Hall passed away at his home early on the morning of July 25, 2008. He was 88 years of age. As a young man he was an avid reader and assembled homemade contraptions from junkyard components. As a fourth grader he told his teacher he would someday work for General Electric, the company of his hero, inventor Thomas Edison. Tracy received his B.S. and then an M.S. in chemistry from the University of Utah and then spent two years as a Navy ensign. Afterwards he returned to the University of Utah and received his PhD in 1948. In 1948 he started work at General Electric Research Laboratory in Schenectady, NY. At GE, Tracy joined team focused on synthesizing diamond in the laboratory. On December 16, 1954, the team became the first to synthesis diamond from carbon using a verifiable and reproducible process. Of the experience Tracy later recalled: "My eyes caught the flashing light from dozens of tiny crystals. My hands began to tremble; my heart beat rapidly; my knees weakened and no longer gave support - I knew that diamonds had finally been made by man." Dr. Hall also invented the tetrahedral and cubic presses in the field of high pressure. Many other diamond-producing companies, based on Dr. Hall's inventions, have emerged worldwide. Dr. Hall was also awarded the prestigious Honorary Lifetime Membership in the Industrial Diamond Association for his life's work. Tracy was a kind and devoted husband and father with seven children, thirty-five grandchildren and fifty-three great-grandchildren. One of his greatest joys was serving as a bishop in the Provo Utah Pleasant View First Ward of the Church of Jesus Christ of Latter-day Saints. Tracy and his wife, Ida-Rose later served a full-time mission to Zimbabwe and South Africa (1982-83). If Tracy set out to have a life as a great scientist, a humanitarian, a spiritual leader and a respected family man, we can all attest … he succeeded.

HALL with first Synthesized Diamond

EDITOR'S NOTE:

I had the honor of meeting Dr. Hall on two occasions and both are etched in my memory as significant moments in time. I first met Dr. Hall June 12, 1998, when The American Society of Mechanical Engineers recognized the Ultra-High Pressure Diamond Manufacturing Apparatus at the General Electric R&D Center as an ASME Historic Mechanical Landmark. Dr. Hall was a member of the original diamond team that used this to create the first reproducible diamond process. Three of the scientists on that team were honored at the ceremony, Dr. Hall, Dr. Herb Strong and Jim Cheney. It was a pleasure talking with him and still seeing the light in his eyes as he recalled those first diamond crystals almost 44 years earlier. The second time I met Dr. Hall was December 16, 2004 for the 50th Anniversary of the First Diamond Synthesis. I remember listening to many of the industries leaders praise Dr. Hall and the diamond team's accomplishment. Jim Cheney, one of Dr. Hall's colleagues on that famous team spoke of the cohesiveness of the group of scientists and the way they complemented each other. We were all lucky to have had this man as part of our history and past. I am sure we all share the loss of this industry icon.



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How The Same Grinder Can Deliver Optimum Value For Both High-Volume and Low-Volume Applications

By: TIM HYKES, Chief Engineer
Cinetic Landis Corp.

Most people would agree with the proposition that job shops and production operations have very different requirements for a machine tool, and that features and technologies with high appeal to one probably have little value to the other. That widely accepted conventional wisdom guides the design of many machine tools aimed at what the builders perceive to be niche markets. But, is it really true?

Or is it possible that the same feature or technology may appeal to both markets for different reasons? And, if the latter is the case, can a builder then design one machine tool that delivers optimum value and productivity at both ends of the spectrum, even though the users define and measure those attributes differently? As it turns out, the conventional wisdom often is not true. It is possible to design a machine with features and technologies that deliver different, but equally valuable, benefits to users at both ends of the volume spectrum. Moreover, the more advanced and sophisticated a feature or technology is, the more likely it is to have strong appeal in both niches and many applications in between. The Landis LT1 camshaft grinder provides a good illustration of these points. Designed primarily for high-volume automotive camshaft production, the LT1 incorporates a suite of advanced technologies, including: Hydrostatic wheelhead ways, cross slide, and wheel spindle; Linear motor technology; Landis CNC6400 OMAC-compliant control system with CNC wheel feed, wheel dressing, and variable speed work drive; Base and machine components optimized for stability; Specifically designed for CBN grinding wheels In addition, the LT1 was designed with a very small footprint, low center height, and short load reach to accommodate cellular installations and automated loading systems. It also has a reduced parts count for improved reliability, and sufficient flexibility to handle crankshafts and transmission components with shaft lengths up to 1,200mm in an optional configuration. Perhaps the best way to see how job shop and high-volume users perceive these features and technologies is to examine each of them individually before looking at the synergistic "package" benefits they deliver.

Hydrostatic Bearing Technology

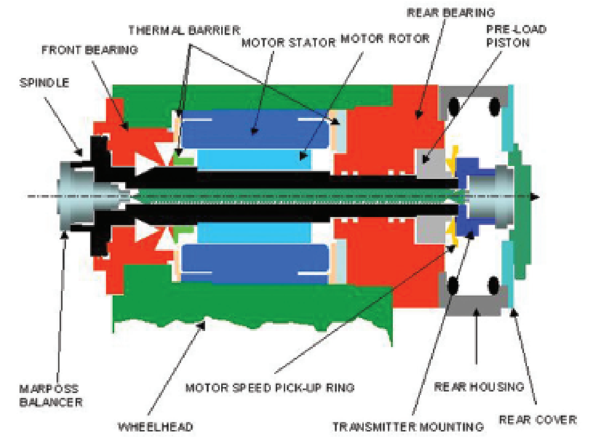
All of the linear ways and the spindle in the LT1 utilize hydrostatic bearing technology. In very simple terms, hydrostatic bearings replace the rolling elements of conventional mechanical bearings with a layer of pressurized oil to separate the two surfaces. They are extremely stiff which translates into outstanding axis damping at microscopic precision levels, and are virtually wear-free. In the high-volume context, the major advantage of hydrostatic ways is downtime elimination. Hydrostatic bearing technology virtually eliminates wear and all of the downtime associated with it. Hydrostatic bearings are at their best in a 24/7 manufacturing environment because the major opportunities for mechanical contact, and thus wear, are during start-up and shutdown. Once they have reached a stable operating state, hydrostatic ways will function reliably as long as they are supplied with oil. The fact that hydrostatic ways are extremely stiff, which promotes accurate axis performance, is also important, but not as much as their durability and reliability. The same is true of hydrostatic spindle bearings. Today's top quality ball bearing spindles can deliver micron-level TIR as delivered from the factory. With good maintenance they may still be doing so after six months of operation, but probably not much longer than that as wear takes its inevitable toll. A hydrostatic spindle, on the other hand, will deliver _ micron TIR from the factory, and continue doing so virtually forever. In the job-shop context, the machine is not likely to be run 24/7 so, while still important, maintenance and downtime are less significant considerations. Here, the precision and stiffness aspects of hydrostatic bearings become the primary benefits because a stiff, precise machine is more likely to meet the "first part/good part" requirement essential for success in today's competitive environment. Users in the middle ground between these extremes will value the various benefits of hydrostatic bearing technologies as they relate to their own operational situation, giving appropriate weight to each. Evaluated from this point of view, production volume becomes a much less important consideration in selecting a bearing technology.

Linear Motor Technology

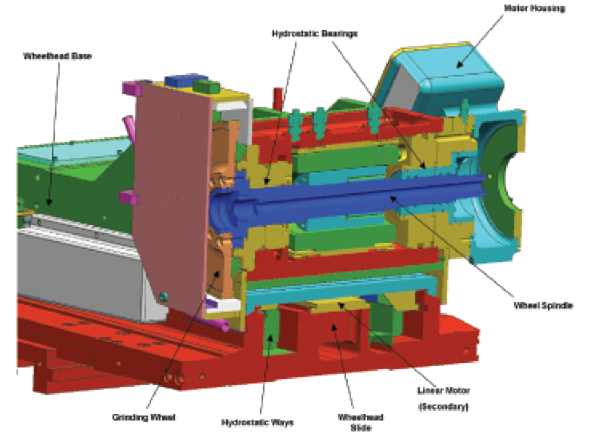
Linear motors are a natural complement to hydrostatic ways because they eliminate the need for any mechanical contact between the moving elements. Again, in a simplification of the technology, a linear motor is essentially a set of opposed electromagnets that is energized slightly out of phase to induce motion. The major advantages of the technology over mechanical drives are performance and reliability. In the job-shop environment, accuracy becomes the primary advantage because it can reduce setup and prove-out time in the quest for “first part/good part” performance. An axis with hydrostatic ways driven by a linear motor will typically deliver accuracy in the range of 10- percent of the expected tolerance for a given machine. In high-volume applications linear motors deliver the same advantages as hydrostatic bearings, the virtual elimination of wear and all of the associated downtime. Their speed capabilities also reduce cycle times, but reliability is by far the most important advantage they offer in high production systems. Another aspect of linear motors that delivers benefits across the whole application spectrum is their ability to instantly reverse direction without generating “reversal error”. This is compliance inherent in the ball screw mechanism that results in a visible imperfection on a cam lobe profile. The specialty manufacturers who produce camshafts for NASCAR and other high-performance engines first noted the fact that linear motors don't generate “reversal error”. It has since become an issue for mass produced engines since it contributes to the NVH signature of the power plant. This is particularly important in high-end luxury vehicles where NVH performance is a critical consumer measure of quality.

Open Architecture Control Technology

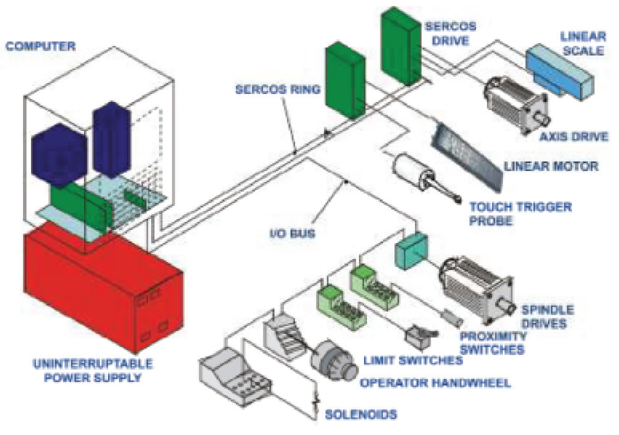
An open architecture control system is in many ways analogous to a modern personal computer. Both are built from a selection of standards based hardware that can be combined into a virtually unlimited number of configurations to meet particular user requirements, and both utilize operating systems and application software that are accessible to users. The high performance 6400 CNC control used on the LT1 grinder is a good example of the genre. Its Microsoft Windows® operator interface provides a familiar graphical environment that facilitates easy programming, set-up and diagnostics with minimal operator training. For a high-volume user, the principle advantage of an open architecture control is that the manufacturing system will not “outlive” the control because it can be continually updated as new components and technologies become available. Proprietary control platforms typically change about every 5 years, leaving the user with an obsolete system that is difficult to maintain, and costly to replace. A new proprietary platform almost always means that new software will be required as well, which typically costs much more than the hardware on which it runs. Like a PC, however, upgrading open architecture hardware does not normally require a corresponding change in software. The use of standards-based components also means that an open architecture control will be compatible with a user's existing networking technology both inside the plant and via the internet. That facilitates off-line programming,



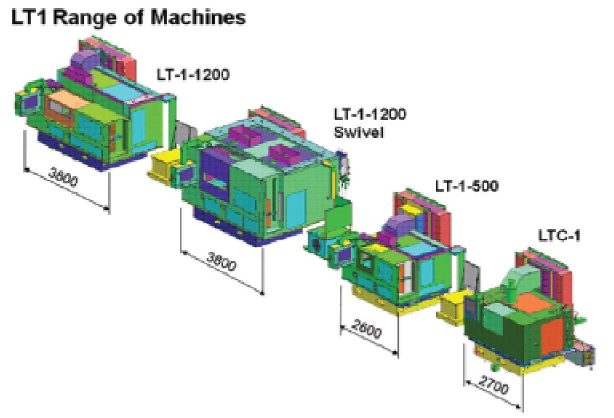
Hydrostatic Bearing Technology



Linear Motor Technology



Open Architecture Control Technology



Machine Layout & Design

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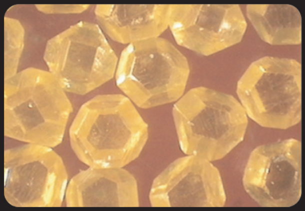

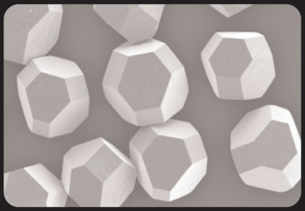

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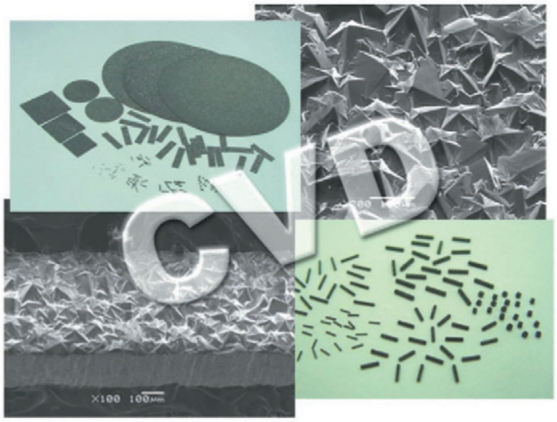

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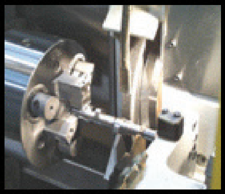
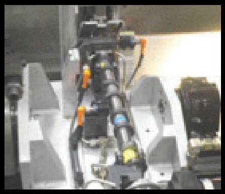
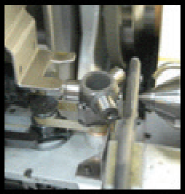
Systemic Synergy



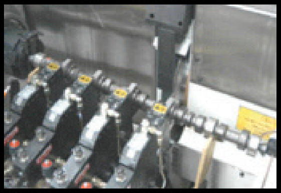
Rough & finish grinding cam lobes & eccentric



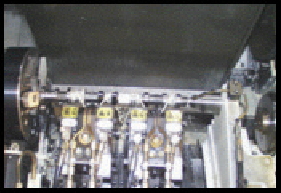
Finish grinding slot on a 4 cylinder camshaft



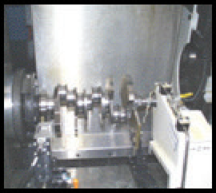
Finishing grinding 3 profiled diameters



Finish grinding 12 cam lobes & eccentric ø on 1200mm shaft length machine variant



Finish grinding 8 cam lobes & 5 journals



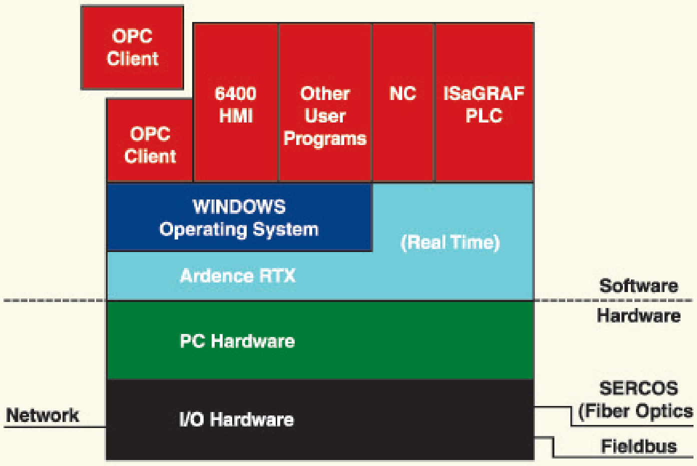
Finish grinding thrustwalls on a V6 crankshaft

Just as each of the technologies used in the LT1 has its own set of application-specific advantages, the machine as a whole also offers different value sets to different end users.

real-time machine monitoring, remote diagnostics and a whole host of other productivity-enhancing capabilities. In the job-shop, the ability of an open-architecture control to store and access an unlimited number of part programs virtually eliminates the need for expensive hard masters. Combined with an accurate machine, the control helps ensure “first part/good part” performance from the production system. Open architecture controls using non-proprietary programming languages also allow users to create their own part programs, which is a major benefit regardless of volume. In many cases waiting for control vendors to create part programs using OEM proprietary languages can add months to a job. Finally, an open architecture control can be specifically configured with the capabilities required for a particular machine tool. Since the OEM control market is primarily focused on turning and machining centers, proprietary controls tend to be optimized for the operations performed on those machines. Applying those controls to a grinder requires many productivity-inhibiting compromises that aren’t necessary with an open architecture design.

Machine Layout & Design

While major features and technologies like hydrostatic bearings, linear motors and open architecture controls have obvious application benefits, other elements of a machine’s layout and design are also important in evaluating its suitability for a particular production environment. The LT1, for example, was designed with a small footprint, low center height and short load reach to accommodate cellular installations and automated loading systems. The small footprint permits the design of very compact, efficient manufacturing cells with short transfer distances to optimize productivity. In the job-shop the same features make this compact, one-piece machine very easy to install without any special foundation requirements. Low center height, short center reach and an optional powered loading door or power front door, make the LT1 equally accessible for gantry or robot loading from the top or front. These same features make it an extremely ergonomic, operator-friendly machine for low volume, manually loaded applications in a job-shop. The LT1 also uses a single hydraulic power unit for all machine functions, unlike some competitive designs that utilize as many as three separate hydraulic fluids to perform various functions on the same machine. This is an obvious advantage for all applications, but is especially important in a job-shop that is unlikely to maintain three different hydraulic fluids in stock.



Systemic Synergy

Just as each of the technologies used in the LT1 has its own set of application-specific advantages, the machine as a whole also offers different value sets to different end users. The high-volume user gets maximum uptime, minimum cycle time and reliable unattended operation. The job-shop gets simple installation, low maintenance requirements, flexibility and first part/good part performance. The open architecture control facilitates use of the advanced Tetra software package that incorporates cam smoothing, automatic work speed generation and thermal modeling to optimize the cam profile before the first part is ground. In one case, the combination of an LT1 grinder and Tetra software has cut minutes from the cycle time of a mid-volume cam production application. Independently, the control, the software, nor the machine could have achieved this kind of result, but the system could, and did. Conventional wisdom says that high-volume users and job-shops have little or nothing in common when it comes to selecting machine tools. But reality says otherwise. Where conventional wisdom would focus the decision making process on volume, a more realistic approach recognizes that the same technology can deliver different, but equally important benefits across the full spectrum of production volumes. Synergy is a much overused word, but in reality the whole really is quite often greater than the sum of its parts. ■

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Highly Automated Diamond Bore Finishing

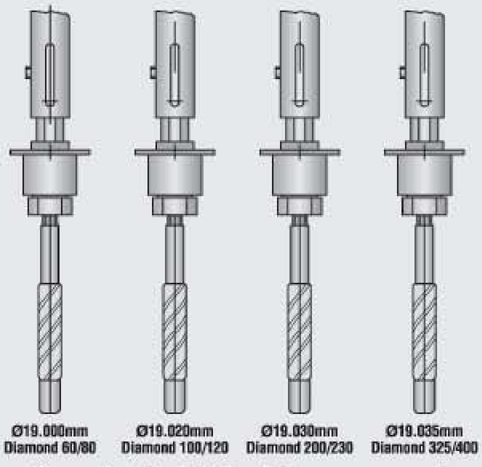
By ROBERT MARVIN, Engis Corporation

Single-Pass Bore Finishing Process

One of the most economical means of finishing the inside diameter of components in production today is with the Superabrasive, Single-Pass Bore Finishing process. The Single-Pass Bore Finishing process involves a series of pre-set diamond coated tools that get passed through a bore with a single in-and-out stroke movement while the tool, part, or both are rotating. The number of tools that are used will vary depending upon the amount of stock to be removed, surface finish requirement, geometrical requirements, and material make up. Generally each tool is set progressively larger in diameter, in reducing increments, while the size of the diamond particles is also reduced. This arrangement allows tools with larger diamond particles that remove larger amounts of material, and tools with smaller diamond particles that have finer surface finish capabilities, to be used progressively for maximum efficiency. The single-pass process is in contrast to conventional honing where the tool or part is reciprocated many times while the abrasive portion of the tool is gradually expanded, then contracted during each cycle. Another difference is in the abrasive bond of the tool. With the single-pass process, a single layer of diamonds is permanently plated onto the tool with approximately 50% of each diamond particle protruding from the bond. The benefits of this are twofold: greater diamond exposure allows for faster cutting/stock removal rates, and because the only wear that occurs on the plated tool come from the diamonds, tool size can be held for extremely long periods of time without adjustment. Conventional honing tools normally utilize stones that have abrasive particles scattered throughout a specific depth in the bond. This type of tool requires the bond to wear so that new abrasive particles can be exposed, and provide a much smaller amount of chip clearance.

Benefits

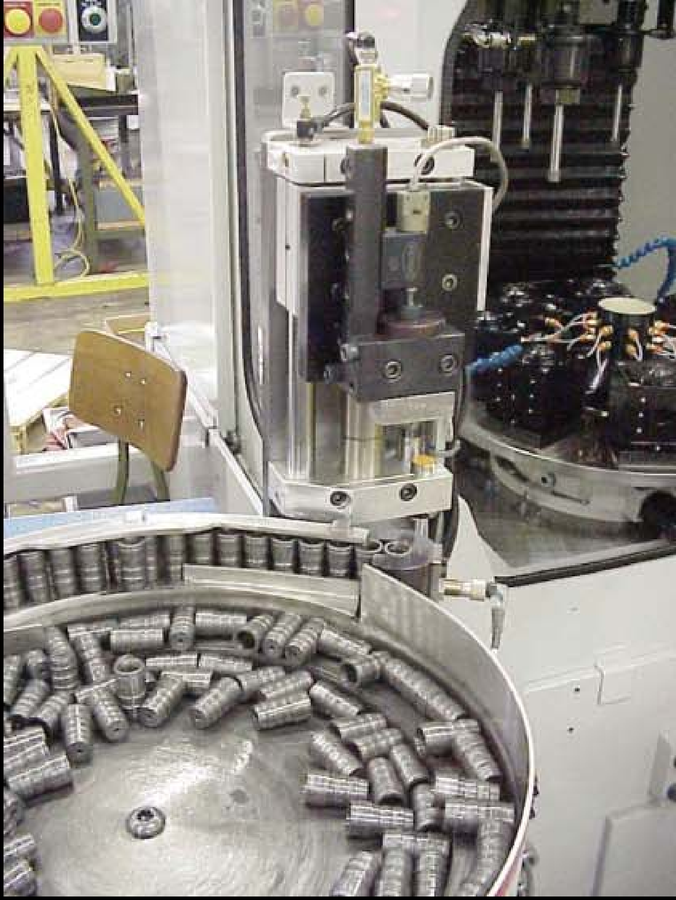
The single-pass process can be tailored to meet the requirements of various applications, and as such, obtain different results. For example, some applications may require very critical bore geometry and allow longer cycle times; while others may have less critical geometry, but require a higher throughput at the lowest possible cost per piece. Higher Bore Precision: The key to the single-pass process is to allow the diamond tooling to follow the existing centerline of the bore to be finished with as little pressure as possible. This is normally done by allowing the tool, part, or both to float. Depending on many other variables, bore geometry to better than 0.2μm (.000008") is possible. Since all of the diamond tools are set to specific sizes and do not require expansion during each cycle, the single-pass process is able to achieve unsurpassed size control in production (1μm with near perfect repeatability). These results are very predictable and repeatable, thus lend perfectly to Statistical Process Control. The diamond portion of the tooling wears very slowly in production which allows for tool life to exceed 100,000 parts in many applications. With an average of four single-pass tools used in a set up, the perishable tool cost is usually under $0.01 per finished part. These cost savings can be so substantial that many high volume applications can justify new equipment and achieve a very quick payback on the investment.



Sample Multi-Tool Arrangement

Automation

Since the Single-Pass Bore Finishing process has become a relatively simple means for

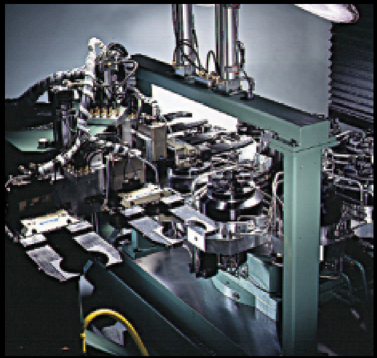


Introduction

In order to successfully compete in today's global market; manufacturing companies must continually face the complex challenge of improving part quality while at the same time reducing over-all costs. How a part is processed and what type of tooling is employed can have a significant impact on the overall profitability and competitiveness of the product. This article will detail methods related specifically to the finishing of inside diameters of parts in production, which various manufacturing companies have found to be successful in meeting this challenge.

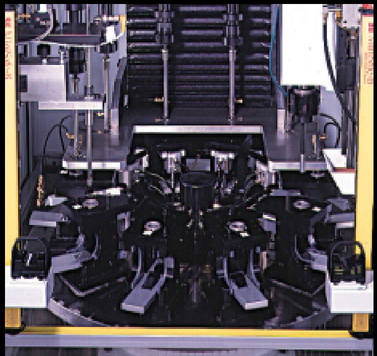
Automated Bore Finishing System

Robotic Load / Unload

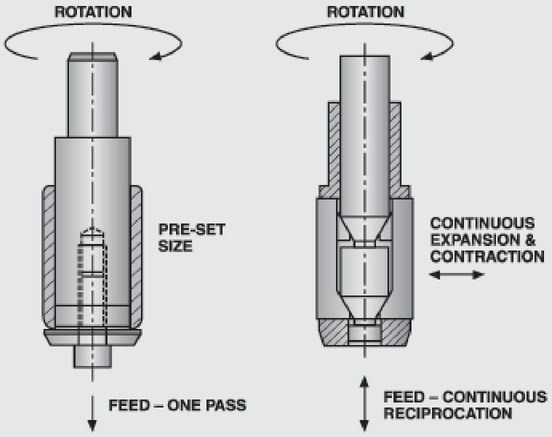


Pick and Place Unit

Post Gauge Within Automation



Post Gauge Within Machine Tool


ROTATION
PRE-SET SIZE
FEED – ONE PASS
ROTATION
CONTINUOUS EXPANSION & CONTRACTION
FEED – CONTINUOUS RECIPROCATION

Single-Pass Movement & Conventional Honing Movement

manufacturing companies around the world to improve bore quality and reduce perishable tooling costs, regions with relatively high labor rates have found it necessary to reduce costs even further through use of various forms of automation. Automation for the Single-Pass Bore Finishing process can be as simple as a bowl feeder with a pick and place unit, all the way up to complete unmanned cells integrated with other processes, and capable of monitoring bore quality and performing automatic size compensation. To properly design and build the best suited automation package for a particular application, many variables must be taken into consideration. These variables include: how the parts will be coming to the system; production rate requirements; how the parts will be oriented and part holding requirements; where the parts need to go after Automated bore finishing system leaving the system; and any auxiliary process procedures that may be required.

Automation Design

Parts can be fed into the automated cell by a variety of means; the most common are Conveyors, Part Trays, Magazines, or Vibrating Bowl. Factors that dictate which means that are utilized include: previous operations; size, shape, and structure of the parts; required production; as well as user preference. The most common types of automation for the load/unload operations are Pneumatic Pick and Place Units, and Robotics. Pick and Place units are the least expensive option and are commonly designed and built for one particular application. Robotics on the other hand may have a higher initial cost, but are very flexible for changing between applications, and can perform various functions as needed. With the addition of vision systems the robotic unit can perform almost anything that an operator could do, only quicker and more efficiently. Other forms of automation for transferring parts into the machine include Linear Transfer Units and Push/Pull Slide Mechanisms.

Outgoing Part Placement

After the Single-Pass Bore Finishing operation has been completed, the parts can be transferred out of the machine and into a variety of accumulation devices or secondary operations. The best option will depend upon the specific application requirements as well as logistical considerations. Options include: Outgoing Conveyors; Accumulation Bins or Tables; Part Trays; and auxiliary operations such as part washing or gauging.

Advanced Features

Automatic post-gauging can be incorporated into the machine tool or automation package. Gauging can be as simple as taking one measurement in a finished part, or as complex as measuring size at multiple axis, and in multiple planes throughout the bore. These measurements are then used to verify acceptable bore quality, and also to perform various SPC calculations. Along with gauging the finished bore size, post gauging can also measure other features, such as straightness, perpendicularity, and "bend & twist" of one bore to another.

Automatic pre-gauging can be very useful in keeping an automated bore finishing system running at peak efficiency by detecting undersize parts that have been loaded into the system, and removing them before ever reaching the diamond tooling. If a part with excessive stock was to go undetected through the system, the diamond tooling could potentially become severely damaged, or at the least experience premature wear. Pre-gauge designs for this procedure include various types of mechanical and air spindles that actually measure the incoming bore size, or spring loaded plug style gauges that detect go/no conditions. Auxiliary gauges can also be added to the system for checking features on an incoming part that have been established

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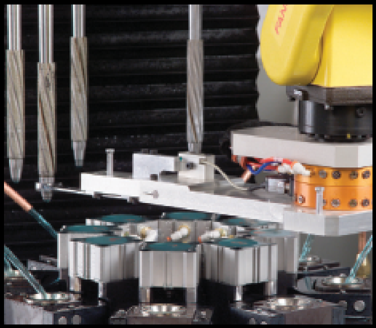
Tooling and Fixture Arrangement

Single-Pass Blind Bore Tooling



Robotic Arm Performing Calibrated Size Compensation

during previous operations. Combining these inspection checks into an automated cell can be a very economical way of further reducing labor costs.

Automotive Timing Cylinder

Recently one precision parts manufacturer tooled up production to produce millions of automotive timing cylinders per year. For the bore finishing operation, multiple automated, conventional style honing machines were setup using Superabrasive honing stones to remove up to 0.08mm of hardened steel material. The length to bore ratio for this part was approximately 2 to 1, with limited clearance of less than 5mm at the bottom of the bore. This initial setup had very limited success and never achieved acceptable capability on bore size or geometry. High perishable tooling cost, as well as costly machine downtime, added to the problem and subsequently forced the manufacturer to search for alternatives. Ultimately a completely new system had to be designed and built. The most drastic change with the new system was to eliminate the conventional honing process and switch over to Single-Pass Bore Finishing. The single-pass machine that was chosen had six spindles which allowed the material to be removed by six, progressively larger, diamond blind bore style tools. The tools were held in floating holders and the parts were held rigidly in collets with controlled pressure to keep from transmitting clamping distortion into the bore.

Parts enter the new system in bulk through a hopper and into a vibrating bowl. The vibrating bowl was designed to orient the parts to the correct direction and feed them through an escapement to a transfer station. At this point value added auxiliary processes, which check the part for overall length, and additional pin hole present confirmation, are run. If the part is acceptable it then gets picked up from a 6-axis robot and loaded into the single-pass bore finishing machine. After bore finishing, the part is transferred to a post gauge where the bore is gauged for size at three elevations, and also for snap ring "present" confirmation. Good parts get transferred out of the system into a bulk accumulator, and parts that fail any of the gauge checks are removed and segregated. Each new system successfully produces 480 finished parts per hour and hold statistical capability to better than a 2 Cpk. Perishable tool costs were able to be dramatically reduced down to $0.01 per part, easily justifying the new

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systems on this savings alone. Other savings, such as reduced labor for inspecting features established on previous operations, and reduced downtime, combined to make this application a great success.

In-Process Tooling Monitoring

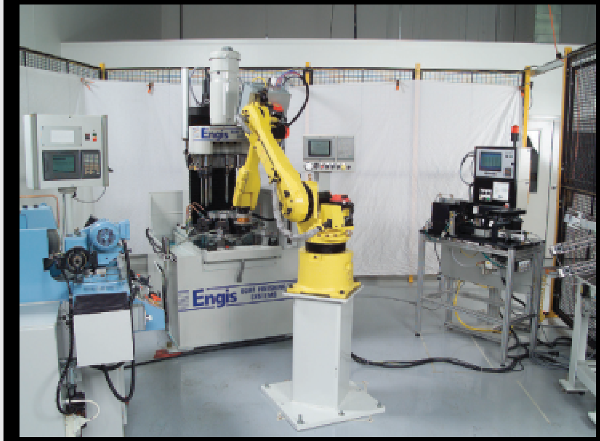
When using a multi-tool arrangement with the single-pass bore finishing process, it is very important to keep each tool set to its correct size. Because of the ability to maintain size for relatively long periods of time, many users simply check the sizes of the semi-finish tooling periodically by manually measuring the bore of a part that was finished with a particular tool. However, for the best results in an automated cell, in-process tooling monitoring should be automated as well. One method of in-process monitoring of the tooling would be to add a gage station after each single-pass tool in the machine. The benefit of this set-up is that the system would continually monitor the cutting size of each tool so that any deviations from the desired size can be corrected before causing any problems. However, this set-up may require up to 50% of additional space in the machine tool and relatively high initial costs. Another, more economical method of monitoring the in-process tooling sizes is by use of a periodic gauge routine. During this routine the system will automatically index parts from each tool station to either a gauge station in the machine, or to a point where the robot will pick up the part and place it onto a gauge probe and take a measurement. After all of the parts from each tool are measured and placed back into the correct location, any required adjustments could be made and the system returned to production. The results from the in-process tooling measurements can be automatically calculated and displayed in a manner so that the operator is informed as to which tools, if any, need adjusting and the amount.

Automatic Size Compensation

As detailed earlier, the slow wear of the diamond tooling enables the process to maintain size for long periods of time without any adjustments and regularly achieve Statistical Process Control to better than 2 Cpk. When the tooling does wear, size is commonly adjusted by manually turning the front pilot nut a calibrated amount. Although this procedure is simple to perform, it too can be automated by use of the robotic automation system or through the machine tool itself. Automatic Size Compensation for each tool can be performed automatically by the machine tool by moving the diamond sleeve up a corresponding tapered mandrel by means of a through-spindle draw bar attached to a separate servo motor. The tooling for this option is more complex than standard Single-Pass tooling, and is available in various designs depending upon the application. Automatic Size Compensation for each tool can also be accomplished by use of a specially tooled robotic system. With this design the robot would automatically change its end of arm tooling when required, and adjust each tool mechanically as an operator normally would. The added benefits of using this design include the ability to use less complicated tooling and usually require less additional costs since the robot is already being used for load/unload duties as well.

Unmanned Cells for Finishing Silicon Nitride Diesel Rollers

In efforts to reduce emissions, Diesel Engines now produce much higher pressures than ever before, resulting in the need for some Engine designs to switch from using Steel Rollers to much harder Silicon Nitride versions. These new Rollers have proven to be very durable in use, but difficult to economically manufacture in production. One manufacturer has recently made great progress in solving this problem and is



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Summary

The Single-Pass Bore Finishing process has made it possible to achieve higher bore precision requirements in production, while at the same time reducing overall cost per piece. With new advancements in tooling, and machinery, this process can now be applied to almost any application, and in almost any material. These applications include:

- Through bores
- Blind bores
- Stepped bores
- Extended Length to bore ratios of greater than 8 to 1
- Hardened materials
- Ceramic and Carbide materials
- Soft Aluminum and Bronze materials
- Titanium and other exotic material

For even further increases in productivity and cost savings, advanced automation systems with additional features such as automatic gauging packages and in-process size compensation can be successfully combined with the Single-Pass process.

currently able to supply Silicon Nitride Rollers at a marketable price. The key was to rethink the entire manufacturing process and automate all of the operations to as great of an extent as possible. For the final finishing operations, multiple automated cells were designed and built combining state of the art bore finishing, grinding, crowning, and gauging; all tied together by a central robot.

Process Details

Parts enter the cells by being mass loaded onto a rotary carousel slug stacker, which automatically presents them to a staging location for pick up. During a cycle, the central robot will pick up a raw part from the staging location and transfer it to a six- spindle, Single-Pass Bore Finishing machine. Here almost 1mm of very hard Silicon Nitride material gets progressively removed over six diamond tools, holding the final bore size within 5 microns, and producing a surface finish of 0.2 Ra or better. Parts are face clamped during the cutting cycle so that perpendicularity can be established between the bore and location face.

Once a part is finished with the bore finishing process, the central Robot then transfers it from the bore finishing machine over to a cylindrical grinding machine, where it is placed onto an expanding mandrel and clamped. The outside diameter is then ground to finish size and concentricity to the bore is established. Next the central Robot removes the part from the expanding mandrel and places it into a crowning machine where a crown of only a few microns is polished onto the outside diameter. The central robot then transfers the finished part from the crowning machine into an automatic post gauging system where measurements are taken for bore size, outside diameter size, face to bore run out, and bore to outside diameter concentricity. If all measurements are within tolerance the central Robot then removes the finished good part and places it back on the rotary carousel slug stacker for mass transfer out of the cell. If any of the measurements taken approach the set control limits, the system will initiate automatic compensation. To automatically compensate size on the single-pass bore finishing machine, the robot first goes through a complete gauge routine, then proceeds to change its end of arm tooling and make any necessary adjustments. Once completed the central robot then changes its end of arm tooling back to the grippers, loads a new part, and continues on with the automatic cycle. ■

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Fall 2008	Machine Tools & IMTS Preview	July 31, 2008
Winter 2008/2009	Polycrystalline cBN & Diamond	Nov. 30, 2008
Spring 2009	Superabrasives Resource Directory	Mar. 31, 2009
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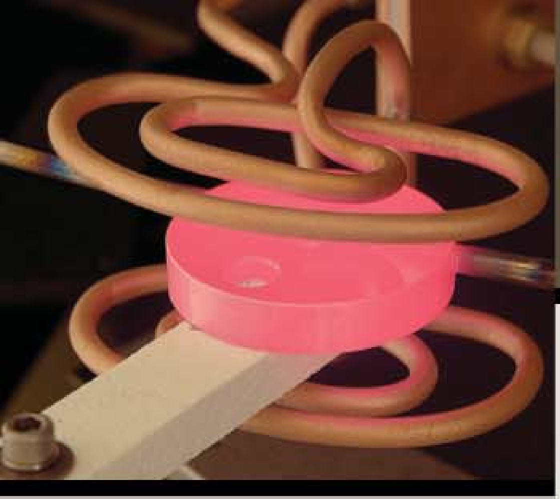

Equipment Solutions for the Brazing of Diamond Tools

By STEVE SKEWES, Induction Atmospheres

BRAZING OVERVIEW

Brazing is the most reliable method of joining diamond to metals. It is also the most widely used and one of the areas where processes are held as trade secrets in most companies. This paper attempts to provide a general overview of brazing diamonds, and an overview of recently developed equipment used for the brazing of the components. Brazing is a method of joining two pieces together using a third, molten filler metal – braze alloy. The joint area is heated above the melting point of the braze alloy but below the melting point of the materials being joined; the molten braze alloy flows into the gap between the other two materials by capillary action and forms a strong bond as it cools. Typically when joining metals, a diffusion bond is created between the two metals to be joined and the braze alloy. Of all the methods available for metal joining, brazing may be the most versatile. Brazed joints have great tensile strength – they are often stronger than the two metals being bonded together. Brazed joints also repel gas and liquid, withstand vibration and shock and are unaffected by normal changes in temperature. Because the metals to be joined are not themselves melted, they are not warped or otherwise distorted and retain their original metallurgical characteristics. The process is well suited for joining dissimilar metals, which gives the assembly designer more material options. Complex assemblies can be manufactured in stages by using filler metals with progressively lower melting points. Additionally a braze alloy may be chosen which compensates for the thermal expansion coefficient differences between two materials. Brazing is relatively fast and economical, requires relatively low temperatures and is highly adaptable to automation and lean manufacturing initiatives. Brazing of diamond to metallic substrates differs significantly from brazing to join metals. Rather than relying on capillary action and a diffusion bond, the brazing of diamonds relies on a chemical reaction.

FACTORS TO CONSIDER WHEN BRAZING DIAMOND:

Much has been written in the literature regarding the brazing of diamond. We are going to highlight the areas that drive the selection of a brazing method and equipment. By far the most important factor to consider when brazing diamond is the graphitization of the diamond. Once the diamond has undergone this transformation, it losses its desired mechanical properties. When graphitization occurs is a function of type of diamond, oxygen level and temperature. For example: Single crystal natural diamond starts the graphitization process at 2910 F (1600 C) in a pure inert atmosphere, 2732° F (1500° C) in a vacuum of 5 x 10-6 torr (5 x 10-4 Pa), 2192° F (1200° C) in a vacuum of 1 x 10-4 torr (1 x 10-2 Pa), and 1832° F (1000° C) in air at atmospheric conditions.

Atmosphere Temperature Graphitization Start of Single Crystal Natural Diamond

Torr	Pa	F	C
760	1x105	1832	1000
1x10-4	1x10-2	2192	1200
5x10-6	5x10-4	2732	1500
Pure Inert		2910	1600

For sintered PCD, graphitization can be enhanced above 1300° F (700° C) when it contains up to 10 volume percent metallic phase. Brazing temperatures for this material are limited to a maximum of 1832° F (1000° C) with slow heating and cooling rates between 1300° F and 1832° F (700° C to 1000° C). While complete graphitization of the diamond will have detrimental effects on the mechanical properties, it is used in the brazing process. Metals do not diffuse and are not dissolved in the diamond. However diamond does form carbides relatively easily. Researchers have discovered that by adding Ti, Cr, Ta, and/or Si to brazing alloys stable carbides are formed that wet and allow the brazing of diamond to many materials. These materials are known as active brazing filler metals. Alloy systems including Cu-Ag-Ti, Cu-Sn-Ti, or Ni-Cr-B are common brazing filler metals for joining diamonds to metals, and ceramics. Very careful control of the temperature during the brazing cycle is not only important in effective wetting but also has a direct effect on the strength of the joint. The joint strength is a function of the kinetics of reaction between the braze alloy and the diamond. The two most important factors are the temperature and hold time to facilitate the kinetics. The objective is to achieve the optimal thickness of the carbide layer. For example: Diamond wafer 0.02 in (0.5 mm) thick and 2 in (50mm) OD was brazed to a cemented carbide substrate in vacuum.

Brazing Temperature

Joint Strength (ksi)	Range (F)	Hold Time (min)
17.4 to 18.8	1616 to 1688	20
13.05	>1688	20
7.2	1616 to 1688	3

Based upon this, it is obvious that the most important attributes needed in a diamond brazing system are temperature and atmosphere control. This was further confirmed by a survey of diamond brazing facilities. These facilities were asked to rank various attributes and to provide a score for each attribute. This allows us to determine relative ranking between the attributes. The results are as follows:

Diamond Brazing Heating System Attributes

Attribute	Points
Temperature Variation/Uniformity	30
Atmosphere Control	25
Temperature Control - Ramp up & down	15
Total Cycle Time	5
Whole Part Heating	5
Energy Efficiency	4
Operating Expense	4
Initial Capital Expense	4
Process Documentation – What happened during the cycle	4
Ease of Maintenance	2
Maintenance Costs	2
TOTAL	**100**

The above survey results confirm the necessity for temperature and atmospheric control to limit the graphitization of the diamond. Based upon these results, it is a given that any brazing equipment must have temperature uniformity/control, and atmospheric control. All of the other attributes such as total cycle time, energy efficiency, etc. could be product

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Some commercial Brazing Filler Metals Used to Join Diamonds with Metals, Ceramics and cemented Carbides

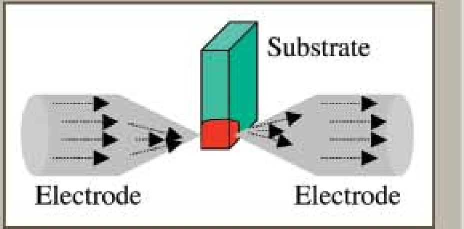
Brazing Filler Metal	Composition Wt%	Solids Temp F	Solids Temp C	Liquids Temp F	Liquids Temp C	Brazing Temp F	Brazing Temp C
Nicrobraze LM	Ni-7Cr-3Fe-4.5Si-3B	1780	970	1832	1000	1850-2140	1010-1170
Metglas MBF-1011*	Pd-40Ni-5Co-4.5Mo-5Si	1556	847	1643	895	1740-1652	900-950
Metglas MBF-15	Ni-13Cr-4.2Fe-4.5Si-2.8B	1769	965	2017	1103	2100-2050	1150-1120
Nicro-B	Ni-15.2Cr-4B	1918	1048	1996	1091	2012-2084	1100-1140
Nicuman 37	Cu-9Ni-23.5Mn	1740	950	1751	955	1760-1832	960-1000
High Temp 095	Cu-9.5Ni-38Mn	1616	880	1697	925	1740-2000	950-1090
Ticusil	Ag-26.7 Cu-4.5Ti	1436	780	1652	900	1688-1760	920-960
Incusil-ABA	Ag-27Cu-13In-1Ti	1121	605	1319	715	1345-1400	730-760
Palnicro 36M	Ni-36Pd-10.5Cr-3B- 0.5Si	1508	820	1760	960	1790-1875	975-1024
Palnicro 30	Ni-30Pd-10.5Cr-2.4B	1725	941	1790	977	1825-1900	995-1035
BrazeTec CB10	Ag25.2Cu-10Ti	1436	780	1483	805	1560-1740	850-950
TiBraze 375	Ti37.5Zr-15Cu-10Ni	1516	825	1535	835	1562-1652	850-900
TiBrazeAL-655+	Al-6.3Cu-0.3Mn-0.2Si-0.2Ti-0.2Zr	1010	545	1190	645	1220-1292	660-700
TiBrazeAL-642+	Al-5Si-0.8Fe-0.3Cu-0.2Ti	1115	602	1190	645	1220-1274	660-690

*Brazing of cemented carbide substrates and cemented carbide with diamonds sintered in carbide matrix +Brazing of diamond coated by Mn or Ti film

Sources: Shapiro, A. Brazing Handbook, 2007, American Welding Society, Miami; Data from Wall Colmonoy Corporation, 2005 Product Catalog, Madison Heights, Michigan: Wall Colmonoy Corporation: WESGO Metals, 2004, Product Catalog and 2008 website, Hayward, California: WESGO Metals; Lucas Milhaupt, 2004, Product Catalog, Cudahy, Wisconsin: Lucas Milhaupt; Brazetec, 2005, Product Catalog, South Plainfield, New Jersey: Brazetec; Metglas website, 2008, Metglas Incorporated; Titanium Brazing, Incorporated, 2005, Product Catalog, Columbus, Ohio: Titanium Brazing, Incorporated.

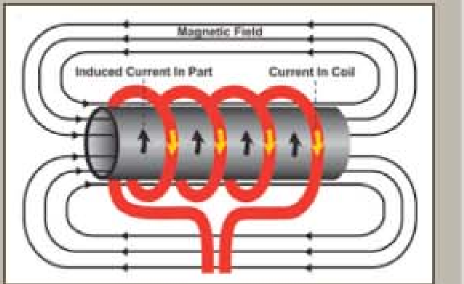
Inert Atmosphere System

High Vacuum Infrared System



Method of Resistance Heat

Electric Resistance Furnace



Induction Method

differentiators between brazing equipment systems. The interesting result was how low the initial capital expense attribute was when compared to others. This is the one attribute that did surprise us, however considering the desired results from the equipment as far as the temperature uniformity and atmospheric control one can understand the one time capital expense to be much lower in scouring. In order to initiate our review of various diamond brazing equipment options, we must first review the braze alloy form, type of control of the atmosphere and sources of heat available in the market.

BRAZE ALLOY FORM

There are two forms that diamond braze filler metals may come in: paste and foil. Braze paste has the alloy mixed with binders or suspending agents. This semi-solid material is designed to be dispensable through a syringe or similar device. The advantage of the paste is its ease of application, however there are a couple of downsides to it. From the economic standpoint, braze paste costs much more per gram of alloy than the solid form. Additionally it must be heated slowly in a vacuum atmosphere to allow for the binder to evaporate. Heating paste too quickly (i.e. direct resistance or induction) will cause the paste to splatter resulting in a poor quality joint. Foil (performs) are solid braze filler metal. This form of alloy is lower cost per gram, and is independent of the source of heat. However it may require additional or more sophisticated fixturing than paste.

ATMOSPHERE CONTROL

There are two effective atmospheric control systems that may be used: 1) Inert Atmosphere, 2) High Vacuum. When referred to in brazing applications, an inert atmosphere is one in which there is very little (<1 ppm) or no oxygen present. Typically the atmosphere is comprised of H, He, N, or Ar or some combination thereof. The general practice for brazing of diamond, is to use an Ar or 95% Ar, 5% H atmosphere. With either of these atmospheres, it is impetrative that all of the oxygen be removed. While there are systems in place in which an Ar cover gas is used during a laser brazing of diamond process, this paper is intended to cover the more prevalent forms of heating and atmospheric control. The most robust method of ensuring that the majority of the oxygen has been removed is to have a roughing pump system which pumps down, the heating chamber, and then the chamber is backfilled with an inert gas. This process is repeated for a total of 3 to 5 cycles to ensure an acceptable atmosphere is achieved. One universal piece of equipment is an inert atmosphere glove box system. These systems have a main chamber that is constantly held at a slight positive pressure of inert gas (Ar or N). A load chamber, also called an antechamber, is located on one side through which the parts are introduced. The antechamber has a roughing pump and follows the above procedure before the parts are introduced into the main chamber. There are two unique aspects of these types of systems. The first is that the system can have oxygen and water vapor monitors integrated in, which will not allow the heat source to be turned on if the prescribed atmosphere is not achieved. Secondly, the inert gas is constantly cleaned and reused in the system, keeping operating costs very low. A variety of sources of heat (infrared, resistance, and induction) may be used in these systems. Alternatively, a purge type of system may be used. Purge type of systems rely on the relative weight of the inert gas in comparison to air for the removal of the oxygen. For example – argon is heavier than air, so it would be introduced into the bottom of the purge chamber. Since it is heavier, it will want to stay at the bottom of the chamber. As more Ar is added, it forces the lighter air molecules out of the top of the chamber. For most types of systems, the quality of the inert gas is very important to have a successful process. The use of a dew point measurement system will identify if there is a low quality of inert gas. These systems may be integrated in, or be a standalone system located with in the facility. It is desirable to have a dew point measurement of less than 50° C. In the recirculation glove box systems, the gas regeneration system can actually clean the incoming inert gas. Generally, the 95% Ar, 5% H atmosphere is used when the heating chamber is not hermitically sealed and oxygen is allowed to leak in. The hydrogen acts as a reducing agent to remove some of the oxygen from the system. Generally speaking, if a system has to rely on the use of hydrogen, then there is a fundamental flaw in the sealing against atmosphere. If a braze paste is being used, it is highly recommended that an inert atmosphere not be used. As previously discussed, as the braze paste is heated, the binders, which are generally polymeric in nature, are evaporated. If the atmosphere does not remove these polymeric compounds, they may become a constituent in the joint thereby reducing its strength. High vacuum systems are generally defined as those systems that operate in pressures of 1 x 10-3 to 1 x 10-9 torr (100 mPa to 100 nPa). These systems are generally composed of either a turbo molecular pump backed up by a roughing pump, or an oil diffusion pump backed up by a roughing pump. Since most brazing processes result in out gassing, most high vacuum systems use an oil diffusion pumped system due to the robustness of the pumping scheme. This is especially true if paste is used as the alloy form. While the initial investment is higher for high vacuum system, the process robustness is much greater. The overall value of these systems must be evaluated.

SOURCES OF HEAT

In general there are six different sources of heat used for the typical brazing process: Flame, Furnaces, Infrared, Induction, Dip, and Resistance. For this discussion, we are going to limit our overview to those methods most wildly used in the brazing of diamonds: Infrared, Resistance, Electric Resistance Furnaces, Induction and Induction Furnaces.

INFRARED

Infrared brazing uses high-intensity quartz lamps to generate electromagnetic radiation wavelengths greater than the visible spectrum. This radiation is absorbed by the part to be brazed. Infrared brazing was developed for the brazing of honeycomb panels. Infrared brazing is effective when there is a high surface area to mass ratio (i.e. honeycomb panels). While the heat input varies as the square of the distance between the assembly to be brazed and the quartz lamp, the lamp does not need to follow the contour of the part exactly. Infrared systems rely on thermal conduction to remove heat from hot spots and to carry the heat to those areas not directly exposed to the lamps. Parts may be placed into a quartz retort or bell jar that can have a protective atmosphere. The quartz lamps are arranged outside of the retort or bell jar and the part is thermocoupled for closed loop temperature control. Proper positing of the thermocouple when using infrared heating is critical to a successful process. This is especially true when trying to braze diamonds onto complex geometries. While nearly 100% of the energy used by the lamp is converted into electromagnetic radiation, not all of this radiation reaches the part. Radiation is converted into not only infrared, but also visible light. Additionally there are significant losses since the lamps are on the outside of a chamber and the parts are on the inside. Maintenance costs are quite high since the lamps must be replaced.

RESISTANCE

Resistance brazing is a process where by the heat generated in the braze joint is a result of the electrical resistance to an electrical current flow. Heat is generated in either the components to be brazed, the electrodes that contact the components or both. Resistance heating is very localized and rapid. It tends to have very poor temperature control with significant differences arising across the braze joint and substrates. Additionally due to the fact that one piece must be done at a time, it can only be considered for very low volume applications.

Company profile

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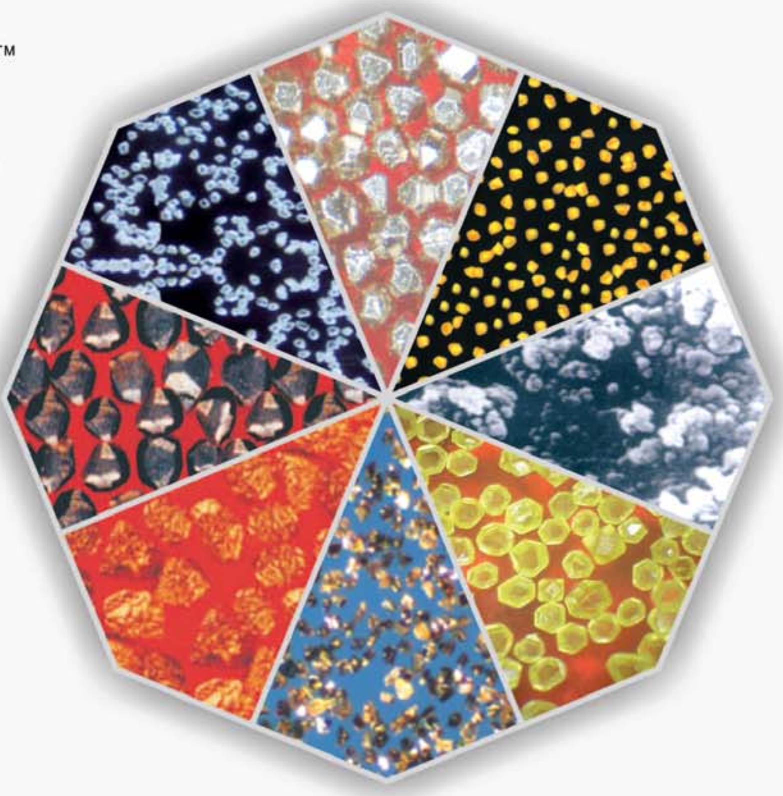

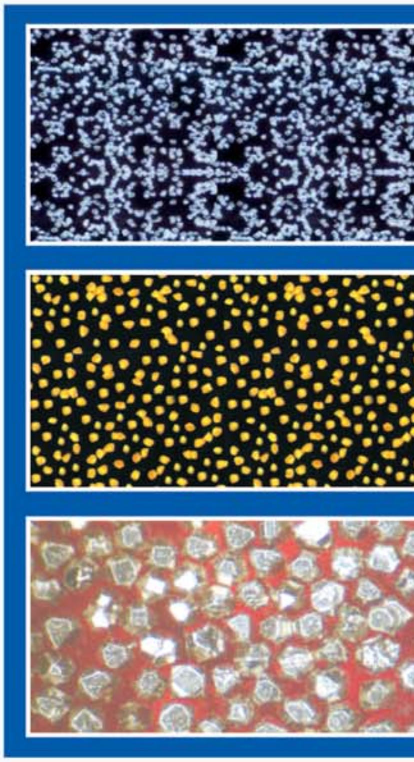

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Resistance brazing is the most energy efficient, and least costly for capital, and maintenance, however given that it produces significant temperature gradients, and is difficult to control the temperature ramp up and down, its use in brazing diamonds is limited to very specific part configurations and very low volumes. Resistance brazing equipment is very similar to resistance welding equipment. Many resistance welding equipment manufacturers produce systems that may be used for brazing as well as welding.

ELECTRIC RESISTANCE FURNACES

A common source of heat for brazing diamonds is radiant heat produced in an electric resistive furnace. Resistance heating relies on a current being passed through a resistive material such as graphite, molybdenum, tantalum, etc. The electrical current is connected directly to the heating element. Heat from the element is then radiated towards the part to be heated. By placing multiple heating elements into a given space, the furnace can have multiple zone control for temperature. For example, a furnace could have 3 different zones of heating, one for each end and one for the middle. The ends will most likely cool faster and heat up slower due to lack of proper radiant heat control within the hot zone. By employing multi zone control, the furnace can compensate for these losses and provide a more uniform heat zone. With the typical insulation packages used, temperature uniformity in these types of furnaces is on the order of ±20° F. Furnaces can have any number of atmospheric control options including inert gas, and high vacuum or a combination. High vacuum pumping times and therefore the total cycle time is partially a function of the insulation used in the furnace. Typically graphite or ceramic "wool" materials may be used which have very high surface to mass ratios. These materials tend to trap oxygen inside of the chamber requiring longer pump down times and may cause out gassing during the heating process. This out gassing may be detrimental to the diamond brazing process if it is not effectively removed by the pumping system. The energy efficiency of electric furnaces range from 10 to 70 percent. Since most of the types of furnaces used to braze diamond would be vacuum furnaces, the bulk of the energy waste is in the conversion losses. Maintenance and operational costs are relatively high for these types of systems. This is due to the fact that the resistive elements must be periodically replaced. The frequency of replacement is a function of operating temperature, hours of operation, and cleanliness of the process. Brazing with paste is a "dirtier" process than foil due to the binders used.

INDUCTION

The basic principal of induction is based upon Faraday's Law. If a secondary of a transformer is located within the magnetic field of the primary, an electric current is induced in the secondary. In a basic induction heating setup, a solid state RF power supply sends an AC current through a copper coil, and the part to be heated is placed inside the coil. The coil serves as the transformer primary and the part to be heated becomes a short circuit secondary. When a metal part is placed within the induction coil and enters the magnetic field, circulating eddy currents are induced within the part. As shown above, these eddy currents flow against the electrical resistivity of the metal, generating precise and localized heat without any direct contact between the part and the coil. For sensitive brazing operations such as brazing diamond, an induction-based system may be fitted with an optical pyrometer to facilitate closed loop temperature control. Through proper selection of the induction heating power supply, temperature controller, and optical pyrometer temperature control of ±2° F is routinely achievable. Temperature uniformity is achieved through coil design. The most effective uniformity can be achieved in round parts. Due to the nature of electrical current path flow, sharp edges could preferentially heat if the proper coil design is not used. Induction coils are routinely placed into both high vacuum and inert atmosphere systems. Alternatively, as with infrared systems, the induction coil can be located outside of a quartz tube. In this set-up the quartz tube houses the part and is atmospherically controlled. The electromagnetic energy from the induction coil penetrates through the quartz tube and couples to the part. Unlike infrared systems, there are no losses through the quartz tube, because the quartz tube is not heated. Due to the mechanism of heating, the typical energy efficiency is on the order of 80 – 90%. Maintenance and operational costs are generally considered some of the lowest between other heating technologies. While the initial capital cost are higher than other systems the total cost per part must be evaluated. With this analysis, induction based systems typically show very high values.

INDUCTION FURNACE

An induction-based furnace is very similar to the resistance-based furnace discussed above with the exception of the heating mechanism. In an induction furnace a graphite susceptor is heated via induction. The susceptor then radiates heat to the part to be brazed. Unlike resistive furnaces, induction based furnaces of sizes typically used for brazing diamond, do not have multiple zones. Temperature uniformity is achieved through coil design and insulation. Typical uniformity in these types of furnaces is on the order of ±15° F. Like resistive furnaces, induction furnaces can have any number of atmospheric control options including inert gas, and high vacuum or a combination. Unlike resistive furnaces, some induction-based furnaces use solid forms of insulation that minimize the surface area thereby greatly decreasing the time required to achieve the desired vacuum level. Additionally, during the outgassing of the brazing process, solid insulation facilitates effective removal of any brazing by products. Very high levels of temperature control are achievable in these types of systems due to the solid insulation schemes used and the fast response of the induction heating system. These systems have a very high surface to mass ratio, which means that they can very quickly respond to desired temperature changes. Alternatively, typical resistance furnaces have very low surface to mass ratios that make them very sluggish with respect to temperature change requests. Induction based systems are more energy efficient than resistance types due to the minimal losses during conversion. Based upon a 50 kW induction system, the typical cost for operation of an induction-based furnace is on the order of $1.00 to $1.50 per hour. This price is dependent upon local energy and inert atmosphere costs. Unlike resistance-based systems, the maintenance costs are relatively low. These induction-based systems do not require the frequency of hot zone replacements that resistance based systems do. This is due to the fact that induction systems are non-contact – they do not require the direct connection of electrodes that resistance systems do. These connections in the resistance-based systems are a source of failure and material degradation.

PUTTING IT ALL TOGETHER

To summarize the individual system attributes, we have provided the following qualitative analysis: Using the 1-5 scale above and multiplying it by the weighted factors from the industry survey, we arrive at the table below. This table pulls together what the industry feels as the most important brazing equipment attributes, along with a qualitative evaluation of various technologies currently available. In this table, the higher the number the better. When considering both the desired equipment attributes and different systems' relative performance to those attributes, the results presented above seem reasonable. Those results being that an induction furnace are the most desirable for brazing diamond whereas direct resistance is the least. Of interesting note is the difference between the resistive furnace and direct induction. Obviously there is significant difference between these technologies in terms of part through put. Direct induction can typically only produce one to four parts at one time. While the cycle time for an individual part is low, if the total number of parts need to be produced per day is high, then this technology is not effective. One must look to a small batch type of system to achieve the effective through puts required.

INDUCTION FURNACE IN DETAIL

General Electric Aviation and Induction Atmospheres developed an induction based high vacuum furnace for the aerospace industry. This system was specifically designed to replace existing large batch vacuum furnaces with a system that can fit into a manufacturing cell and maintain the tact time for the cell. ■

INDUCTION BASED HIGH VACUUM FURNACE

This furnace has the following characteristics:

Temperature Uniformity: ± 15° F • **Atmosphere Control:** Ultimate Vacuum: 3 x 10-6 torr, Leak Rate: <5x10-4 torr/hr • **Temperature Control – Ramp up & down:** Max Up Rate: 200° F / Min, Max Down Rate: 110° F/ Min from brazing temperature to 400 F • **Total Cycle Time:** Typically 30 to 45 min with a 7 min braze temperature hold • **Energy Efficiency:** 85 % • **Operating Expense:** approx. $1.50 per hour • **Initial Capital Expense:** $160,000 to $220,000 • **Process Documentation:** Paper or Video Chart recorder, Excel downloaded to network, PCMCI Card • **Whole Part Heating:** Yes • **Ease of Maintenance:** All maintenance items located on one side of system • **Maintenance Costs:** Typically <$3,000/yr

There are many different factors that go into selecting a piece of equipment to braze diamond and there is not one piece of equipment that can be used universally. The factors which must be considered are (not in any order): • required production volumes • braze alloy form to be used • how robust are the braze components • what is the brazing temperature range (wide or narrow). Based upon these factors, one can start to determine the required temperature uniformity, atmosphere / temperature control requirements and cycle times. These required heating systems attributes can lead you in a direction from which working with an equipment supplier you can evaluate the net present value of each alternative solution.

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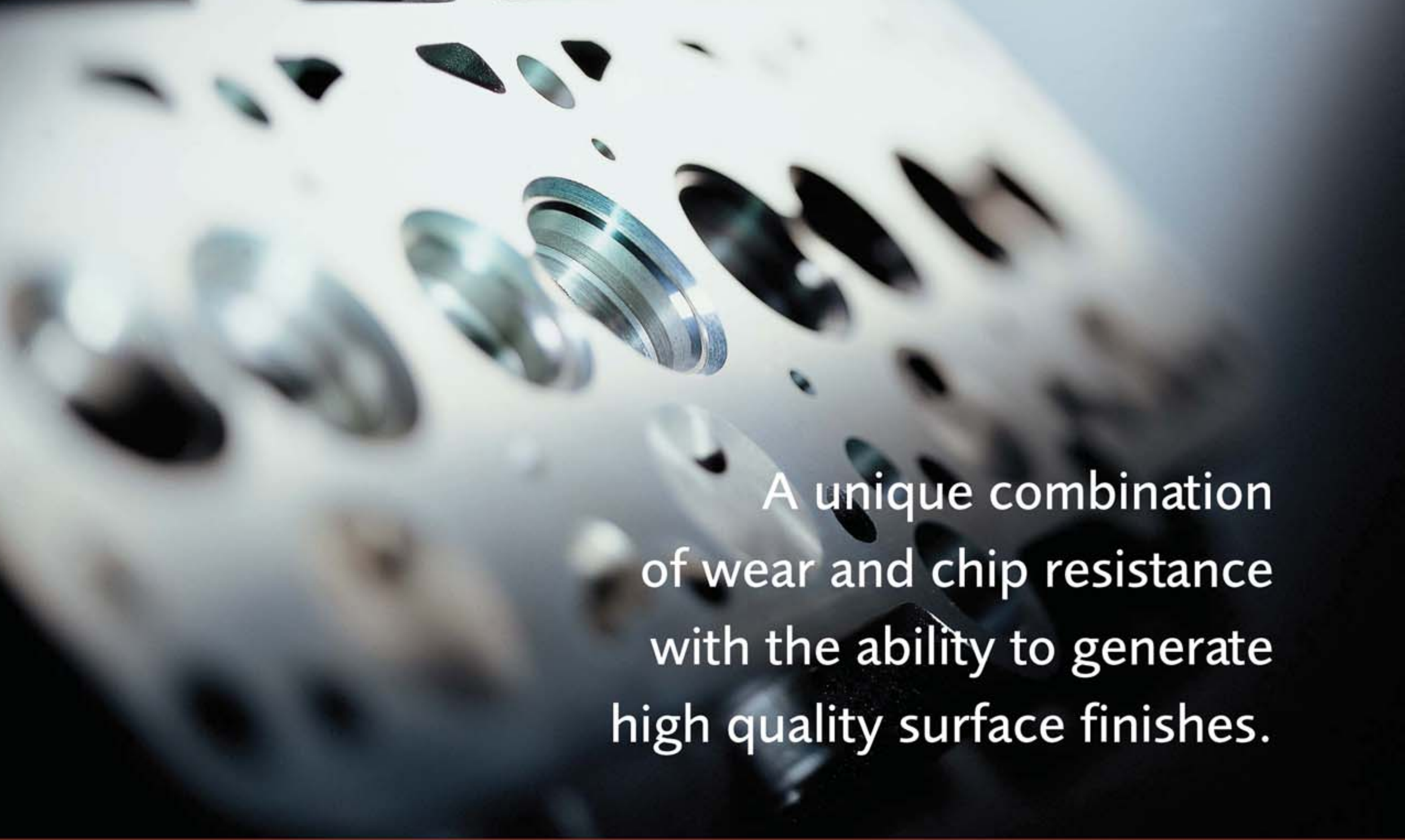

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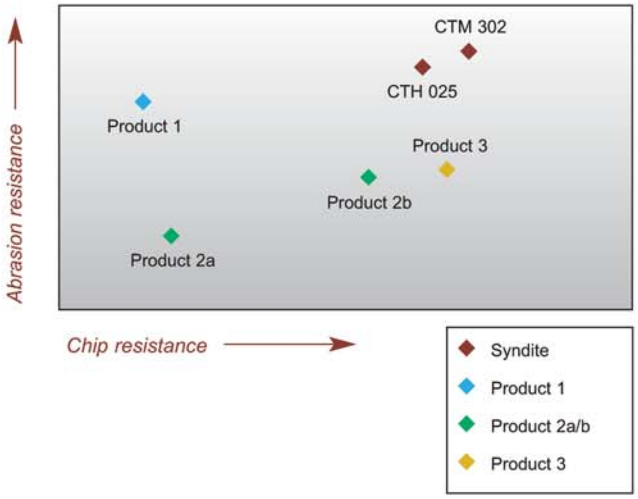
ABRASION RESISTANCE vs CHIP RESISTANCE



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